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MEASUREMENTS OF PARAMETERS OF WATER AEROSOL OBTAINED BY EXPLOSIVE METHOD

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Abstract. *In this article we have presented the results of the military training area measurements concerning the water aerosol obtained by explosive method, which is very good medium to extinguish an intermediate area fire. A dependence of the aerosol cloud diameter and shock wave pressure on the delay between main and upper charge detonations has been investigated. The obtained results allowed to estimate values of time delays guarantee highest efficiency and safety of firefighting system.*

Keywords: pressure measurement, shock wave, firefighting, water aerosol

POMIARY PARAMETRÓW AEROZOLU WODNEGO WYTWARZANEGO METODĄ WYBUCHOWĄ

Streszczenie. *W artykule przedstawiono wyniki pomiarów poligonowych dotyczących tworzonego metodą wybuchową aerozolu wodnego, który jest bardzo dobrym medium do gaszenia pożarów obszarowych. Badano zależność ciśnienia fali uderzeniowej oraz średnicy chmury aerozolu od opóźnienia czasów detonacji ładunków wybuchowych umieszczonych wewnątrz kapsuły będącej źródłem aerozolu. Uzyskane wyniki pozwoliły określić wartości opóźnień spełniających kryteria najwyższej efektywności i gwarantujących bezpieczeństwo.*

Słowa kluczowe: pomiary ciśnienia, fala uderzeniowa, gaszenie pożarów, aerozol wodny

Introduction

The paper presents the results of the research obtained during the military training area tests of spreading of the water aerosol obtained via explosive method. Using the mist systems is very effective solution applied in small commercial equipment [10] to extinguish relatively small fire (houses, cars, apparatus under high voltage, etc.).

Water aerosol due to the explosion is a very effective in extinguishing of the area fires with use of a helicopter. In such a case the water capsule with the explosive charge inside is transported to the fire site by the helicopter on a forty meters long line. Next the capsule is released and detonates on the programmed height over the ground, in this way enabling the covering of the fire source by the aerosol [7].

The aerosol parameters (droplets diameter, aerosol cloud diameter) depend on the type of the used explosive charge, its energy, geometry etc. [2, 3, 6]. To obtain the smaller droplets diameters gives the higher extinguishing efficiency. On the other hand, the larger diameter of the aerosol cloud allows for lower number of the helicopter flights over the fire source [7]. The presented paper focuses on the examinations that were addressed to reaching of the largest aerosol cloud diameter maintaining its proper density.

1. Structure of the water capsule

As mentioned, the source of the aerosol was a water container (capsule) inside of that an explosive charge was placed, precisely two charges: main charge formed around the capsule axis and auxiliary charge fasten in the upper part of the capsule (Fig. 1).

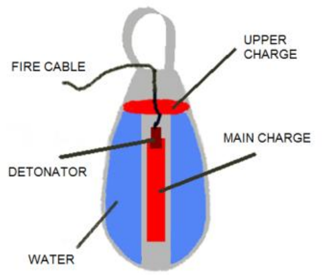

Fig. 1. The schematic cross-section of water capsule

The upper charge is detonated with delay with respect to the detonation of the main charge, and it is aimed at detaining of the aerosol cloud expansion in undesirable direction (opposite to the fire source).

A detonator is composed of a plastic pipe being a body with electronic equipment put inside; protective – arming and pyrotechnic (Fig. 2).

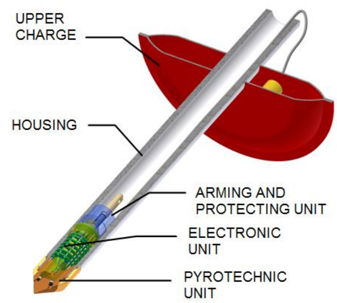

Fig. 2. The detonator together with upper charge

2. Research stand

The research stand is presented schematically in Fig. 3. A bag containing water and explosive charge was hanged on the mobile crane arm at around 8-10 m height, in the center of the line determined by calibration poles distanced of 40 m. At a distance of 150 m from the bag axis, at the end of the line section perpendicular to the line determined by the poles, a fast camera was installed and it registered the cloud expansion process with frequency of 250 fps (frames per second), i.e. in the 4 ms periods. Additionally the whole explosion course was registered by a HDV camera.

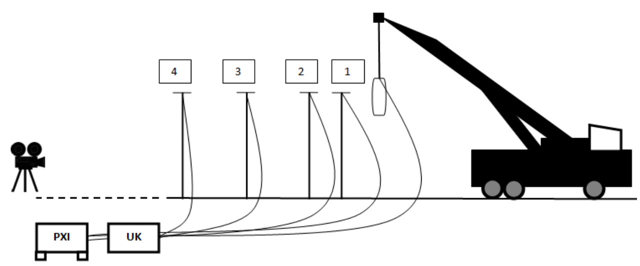

Fig. 3. Scheme of the research stand

On the poles of 8 m height at distances of 5, 10, 20, and 30 m from the explosion axis, four piezoelectric sensors (1-4, Fig. 3) were placed and coupled with suitable signal conditioning system PA16000D (UK, Fig. 3) [12] and with industrial NI PXI computer [11]. The computer served as a data acquisition and processing unit.

Each of the sensors was installed in pencil-like case (Fig. 4) a cone of that was directed into the explosion axis, which prevented detachment of the sensor from the pole by the wave front. A working area of the sensor was placed on one of the case side.

Fig. 4. The dynamic pressure sensor [14]

According to relatively large pressure differences in the wave front at different distances from the explosion axis, the sensor placed nearest to the axis (sensor #1) was characterized by the broadest spectrum (and smallest sensitivity) and sensors 3 and 4 placed far from the axis, contrary, by the largest sensitivity with narrower spectrum. The pressure sensors parameters are presented in Table. 1. The setup for wave front pressure measurements was triggered by short circuit sensor placed inside of the explosive charge.

Table 1. Parameters of the pressure sensors

Number of sensor	Sensitivity K_1 [mV/kPa]	Maximum pressure [MPa]	Resolution [kPa]	Expanded uncertainty $U_r(K_1)$ [%] (95 %)
1	0.149	34.5	0.69	1.3
2	2.8	34.5	0.001	0.8
3	15.1	6.9	0.069	0.8
4	13.7	6.9	0.069	1.3

In figure 5 are presented photos of actual situations in the research stand during one of tests – few, several and several tens milliseconds after detonation.

It is seen that the most of the developed aerosol cloud assumes the form of relatively flat disc. Properly selected value of the delay between detonation of the main charge and auxiliary charge allows to maximal flattening of the cloud.

3. Measurements

Earlier research performed for three different types of the explosive charge: Saletrol (ANFO), Emulinit [13] and plastic explosive (C4) showed that the Emulinit is most efficient in creation of the aerosol cloud [3, 6]. By the way it appeared that the excessive increase of the explosion energy does not lead to increase of the cloud diameter, but even results in its distinct diminishing.

Taking this into account our research has been performed only with one type of the explosive – Emulinit, of limited energy. A dependence of the aerosol cloud diameter and shock wave pressure on the delay between main and upper charge (Fig. 1) detonations has been investigated.

Fig. 5. The research stand during capsule's explosion

3.1. Cloud diameter measurements

Exemplary plots presenting comparison of the results for different delay times and the same explosive charge energy are depicted in Fig. 6, 7, and 8. As seen, in all the cases an overall shape of the plot is the same, and in particular, the cloud diameter is stabilized after 1.5 – 2 s from explosion.

Measurement uncertainty of the cloud diameter can be influenced by errors connected with:
1) situation of the point of reference,
2) ambiguous determination of the water aerosol cloud spatial range – a difference between D1 and D2 (Fig. 9),
3) resolution of the picture registered by the camera,
4) an influence of the wind on spreading of the cloud.

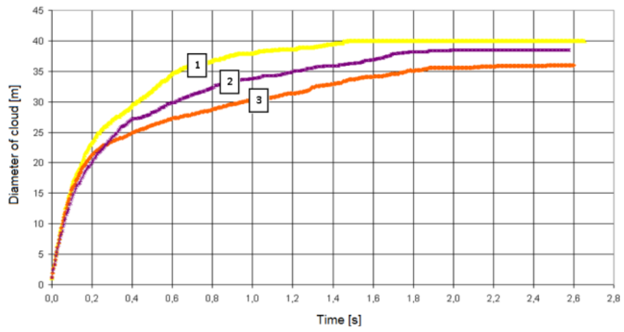

Fig. 6. Cloud diameter as a function of time for the same water capsules (1200 kg, Emulinit ,7,3 MJ). 1 – delay between main and upper charge detonations 2 ms, 2 – delay 0 ms, 3 – delay 20 ms.

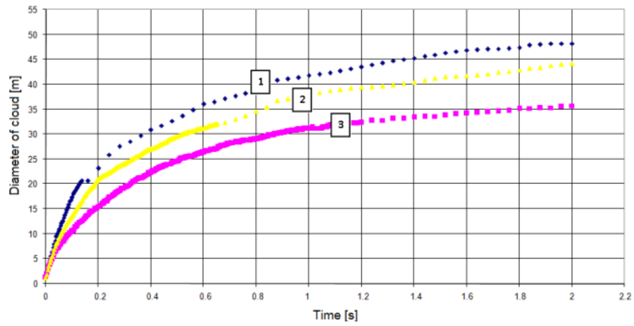

Fig. 7. Cloud diameter as a function of time for the same water capsules (1200 kg, Emulinit ,10,8 MJ). 1 – delay between main and upper charge detonations 4 ms, 2 – delay 8 ms, 3 – delay 12 ms

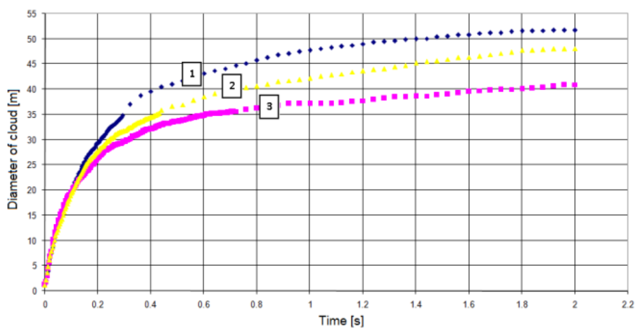

Fig. 8. Cloud diameter as a function of time for the same water capsules (1200 kg, Emulinit, 16,6 MJ). 1 – delay between main and upper charge detonations 8 ms, 2 – delay 16 ms, 3 – delay 20 ms

According to the large distance between the camera and the water capsule the error connected with the situation of the point of reference is negligibly small.

Analyzing a number of tests it has been found that the maximal error of the cloud diameter measurement can be associated with a cloud spreading time, for the time over 2 sec it is on $\Delta x_2 = 2$ m.

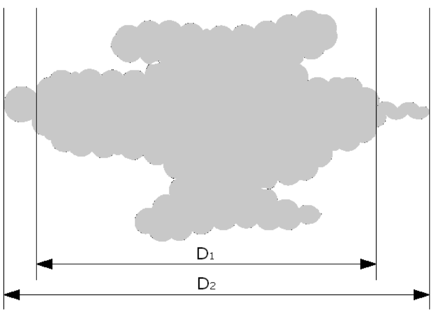

Fig. 9. Measurement of water cloud diameter

To registration of the spreading of the aerosol cloud a fast camera was used, of 1024x1024 dpi resolution and covering an area of 50 m width. According to that an error of distance measurement is 0.05 m:

$$\Delta x_3 = \frac{50\,\mathrm{m}}{1024} = 0.05\,\mathrm{m}\,. \tag{1}$$

Estimation of the error resulting from the wind influence is a tough task because a series of measurements for different speeds of the wind with maintained identical all others parameters and ideal cloud shape. To some extent this error is reflected in an asymmetry of the cloud forming around the water capsule axis and due to the measurement of the overall cloud diameter the error is minimized, so as such it is not taken into account in calculations.

Finally the combined standard uncertainty has been calculated as [1, 8]:

$$u(x) = \sqrt{\left(\frac{\Delta x_2}{\sqrt{3}}\right)^2 + \left(\frac{\Delta x_3}{2\sqrt{3}}\right)^2} \approx 1.2\,\mathrm{m} \tag{2}$$

Based on the measurements performed for different capsule capacities and energy of the explosives one can determine a desirable value of delay: from 2 ms to 4 ms. Using larger delays as well as eliminating them resulted in diminishing of the cloud diameter of the generated aerosol.

3.2. Shock wave pressure measurements

Measurements of the parameters of the shock wave forming during explosion did not reveal substantial differences in pressure values and profiles of the signals registered by computer. At any rate an abrupt pressure increase occurs in the sensor vicinity (overpressure) and then pressure decrease (underpressure) and return to the equilibrium state – ambient pressure.

In figure 10 one of typical pressure courses for explosive charge of 10.7 MJ energy and 2 ms delay is presented.

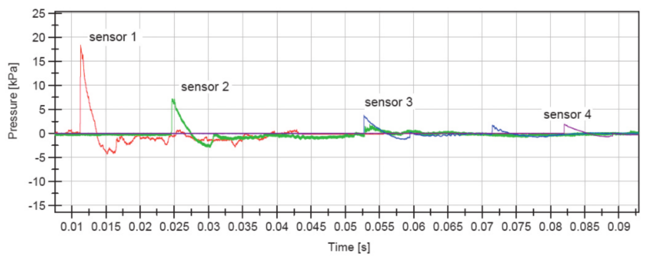

Fig. 10. The shockwave pressure time profiles

In the case of charges of smaller energy and simultaneously – longer delay of detonation in some tests an additional pulse shifted in respect to the main pulse was observed (Fig. 11).

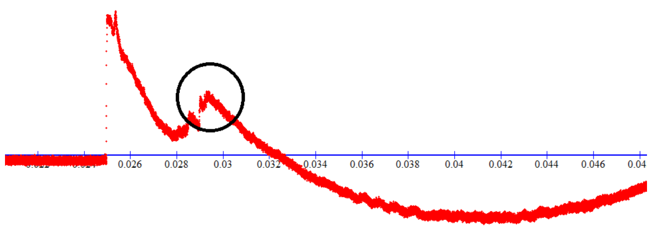

Fig. 11. The part of the pressure time profiles for sensor no. 1

Table 2 lists the results of the pressure measurements. The only substantial difference in the pressure values (~ 20%) has been observed in the test performed without upper charge.

The pressure measurements uncertainty is connected with errors of sensors and errors of measurement chain – signal conditioning system and input analog card.

The value of the pressure can be determined using the following relation:

$$p = \frac{U_2}{K_1 K_2}, \tag{3}$$

where K_1 is a coefficient of the pressure/voltage processing, U_2 is measured voltage and K_2 is amplification of the signal conditioning system.

The value of the sensors pressure measurements uncertainty has been determined based on the value of expanded uncertainty taken from calibration certificate (Table 1).

Table 2. The values of pressure registered by the sensors 1-4 (Emulinit, 10784 kJ, mass of the capsule 1200 kg)

Time delay [ms]	Number of measurement point			
	1 [kPa]	2 [kPa]	3 [kPa]	4 [kPa]
- (without upper charge)	19.7	6.8	4.0	1.8
0	26.1	8.5	4.9	2.1
2	27.6	9.0	4.7	2.3
4	25.1	8.6	4.6	2.0
8	23.5	7.7	4.4	2.0
12	24.3	8.1	4.5	2.2
16	24.7	8.3	4.3	1.9
20	23.9	8.5	4.6	2.1

The value of measurement chain uncertainty has been determined based on the maximum permissible error of the input card ΔU_2 = 2.44 mV and permissible error of the signal conditioning system amplification δ_{K2} = 0.5 %.

The overall uncertainty of the complex measurement has been evaluated based on the following expression [1, 8]:

$$u(p) = \sqrt{\left(\frac{\partial p}{\partial K_1}\right)^2 u^2(K_1) + \left(\frac{\partial p}{\partial K_2}\right)^2 u^2(K_2) + \left(\frac{\partial p}{\partial U_2}\right)^2 u^2(U_2)} =$$

$$= \sqrt{\left(\frac{-U_2}{K_2 K_1}\frac{U_r(K_1)}{2*100}\right)^2 + \left(\frac{-U_2}{K_1 K_2}\frac{\delta_{K2}}{\sqrt{3}*100}\right)^2 + \left(\frac{1}{K_1 K_2}\frac{\Delta U_2}{\sqrt{3}}\right)^2}, \tag{4}$$

The maximum uncertainty values for individual sensors were: $u_1(p)$ = 0.22 kPa, $u_2(p)$ = 0.067 kPa, $u_3(p)$ = 0.026 kPa, $u_4(p)$ = 0.021 kPa.

4. Summary

The performed research allowed to determine the value of the auxiliary charge detonation delay with respect to that of the main charge, which enabled the generated aerosol cloud to achieve the maximum diameter. Increase of the aerosol cloud diameter with simultaneous decrease of its height does not change the density of the covering the fire by the aerosol, so that the extinguishing efficiency is unchanged, but the area of territory to be extinguished becomes larger. Higher values of the wave front pressure can affect the effectiveness of the oxygen elimination from the fire area, although they can be dangerous for the objects being in the vicinity of fire. The values of the overpressures generated at a distance of 30 m from the source of explosion, obtained in the described tests, can be treated as generally safe either for people or for buildings [4, 5, 9].

The research on one of the alternative methods of fire extinguishing, leading to increase of its effectiveness, fits to the pro-ecological activity, because it enables protection of the forest and agricultural areas as well as diminishing of the carbon dioxide emission with simultaneous limitation of the water volume to be used up.

5. Acknowledgments

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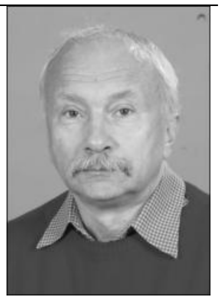

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